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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE		3. DATES COVERED *(From - To)*
	Final		15 April 2001 - 15 Feburary 2004

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Operating System Support for Virtual Machines with Quality-of-Service Provisions	
	5b. GRANT NUMBER
	F49620-01-1-0304
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Joseph Pasquale	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
University of California, San diego 9500 Gilman Drive La Jolla, CA 92093-0114	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
Air Force Office of Scientific Research 4015 Wilson Blvd Mail Room 713 Arlington, VA 22203	AFOSR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A. Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20040706 072

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Joseph Pasquale
U	U	U	UU		19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Cover Page Information

2. Report Date: 6/21/04

3. Report Type: Final report

4. Title: Operating System Support for Virtual Machines with Quality-of-Service Provisions

5. Funding Numbers: F49620-01-1-0304

6. Authors: Joseph Pasquale

7. Performing Organization: University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0114

8. Performing Organization Report Number: 95-6006144

9. Sponsoring Agency: AFOSR

10. Sponsoring Agency Report Number: ???

11. Supplementary Notes: none

12a. Distribution Statement: ???

12b. Distribution Code: ???

13. Abstract

We are investigating system software mechanisms that support remote execution of mobile code (e.g., agents), with the goal of producing a middleware system design and implementation that is realistically deployable in and integrated with the current Internet and Web environment. Our system allows the development of application software structures that promote higher performance, better reliability, and improved security. Our work is especially relevant for end-user client devices that are mobile and wireless, and that need to interact with servers via established Internet and Web protocols. This work is especially applicable in the context of distributed systems with mobile agents, and supplements our previous AFOSR project on System Support for Mobile Agents.

14. Subject Terms: Software, Distributed Systems, Mobile Code

15. Number of Pages: 5

16. Price Code: ???

17. Security Classification of Report: ???

18. Security Classification of this Page: ???

19. Security Classification of this Page: ???

20. Limitation of Abstract: ???

FINAL REPORT

Operating System Support for Virtual Machines with Quality-of-Service Provisions

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June 2004

ABSTRACT

We are investigating system software mechanisms that support remote execution of mobile code (e.g., agents), with the goal of producing a middleware system design and implementation that is realistically deployable in and integrated with the current Internet and Web environment. Our system allows the development of application software structures that promote higher performance, better reliability, and improved security. Our work is especially relevant for end-user client devices that are mobile and wireless, and that need to interact with servers via established Internet and Web protocols. This work is especially applicable in the context of distributed systems with mobile agents, and supplements our previous AFOSR project on System Support for Mobile Agents.

OBJECTIVES

1. Understand the strengths/weaknesses of existing mobile code systems
2. Design a middleware system that support flexible remote execution with quality-of-service provisions
3. Implement the system and evaluate its performance

STATUS OF EFFORT

The research is now complete, and we have completed all of our objectives. In the following section, we describe research highlights and accomplishments.

ACCOMPLISHMENTS

Our primary accomplishment has been the development of a remote execution faculty that extends the well-established client/server model of distributed computing to support a third location of processing by software modules that execute at an intermediate point between client and server. This point is determined based on its expected advantages in terms of performance, reliability, security, or possibly other factors. This intermediate

point is a machine capable of hosting mobile code objects that will be executed by a virtual machine at that host. In most of our work, we have assumed the widespread availability of Java Virtual Machines, with the intent of hosting Java-based mobile code objects sent by clients to interact with servers. Our main contributions are the system software support structures that enable movement and controlled execution of the mobile code, and controlled communication between it and the client and server to which it relates.

To elaborate on our approach, we have three parallel tracks to achieving our goal. The first is the design of a basic client/server "Extension" system, that allows clients to send Java code objects to an intermediate server and execute. It is basically a "send-and-execute" model of distributed computing, giving us a basic remote execution mechanism. This is in contrast to assuming the availability of (or supporting) a general mobile agent system, which is difficult to deploy. Our "limited mobile code" system is easily deployed, and enables one to build applications that can benefit from many of the expected advantages of a mobile agent system without the complexities.

Our second track is to focus on intermediate processing to support client-specific customization for Web-based applications, which is an important special case of more generic client/server computing on the Internet. Our goal is to provide better support for the wide-range of user devices for Web access, such as PDAs and other "resource-challenged" devices that connect to the Internet via a wireless link. Rather than changing all Web content, the idea is to interpose "Web Stream Customizers" that will transform the legacy content to match the more limited display and communication capabilities of these devices. This system assumes a client that is a Web browser, and that initiates an interaction with a Web server, resulting either in the obtaining a document or executing a separate Web application to carry out a more complex transaction. Like the Extension system, we allow that interposition of a processing module that can customize the result of the Web server for the client. By assuming this limited form of interaction and limiting ourselves to HTTP as the basic protocol, the programming and execution models for the mobile code objects are even simpler than those of the Extension system, and therefore much more likely to be deployed and used. Indeed, we view the Customizers as a very important special case of Extensions; in fact, the Customizer system can be theoretically built on top of the Extension system, although at present it is implemented independently (in fact, our plan in the next year is to do the former).

Finally, our third track has been to explore the process of designing mobile-code-based applications, to find ways of simplifying and automating it. Clearly, mobile-code is a foreign concept to most programmers. We believe one of the difficulties of using mobile agent systems, and why they have not yet gained widespread acceptance, is this problem. Consequently, we are investigating the concept of mobile-code "behavior patterns" which codify basic patterns of movement and communication within the extended client/server distributed computing model we have assumed. A programmer would select a pattern that best matches how they expect their mobile code object to behave, provides it with parameters (such as where to move, who to communicate with, as well as application-specific code), and all the complexities of movement and communication are taken care

of by the pattern, simplifying the programming process. This system is being designed to work on top of not just our locally developed mobile code systems, but any general mobile code (mobile agent) system.

Regarding the Extension system, its design consists of both an API to which clients are programmed and a backend that carries out the semantics of the API. We have completed a distributed implementation of the system. The distributed implementation allows multiple servers to be utilized in providing to clients the resources on which Extensions execute. To help evaluate the usability of the system, we have developed a number of applications that made use of the Extension System. For example, in one application we explored the use of Extensions for improving the usability of low-powered, wireless devices, such as the Compaq iPaq Personal Digital Assistant. The iPaq is outfitted with a wireless network card that enables access to a user's desktop machine. The slow speed of the network card and the portrait orientation of the device's display makes simple Web browsing awkward. An Extension is employed in this application to serve two purposes. In order to reduce the bandwidth over the wireless link, the Extension selects a portion of the desktop to display that equals the size of the iPaq's screen. The portion of the desktop displayed is selectable by the user. In addition, the Extension also rotates the desktop to enable use of the iPaq in a landscape orientation. The availability of this Extension improves the Web browsing experience significantly, and its development provided us with valuable experience in using and improving the Extension system. We are currently evaluating the system's performance, and will present our results in a report we plan to publish.

Regarding the Web Stream Customizer system, we have completed its design and implementation. The Customizer system exploits the Web's proxy capabilities, allowing Customizers to be seamlessly integrated with the basic Web transaction model. The implication is that Customizers work within the Web framework that exists today, with no required code modifications to Web browsers or Web servers. The immediate benefits of Customizers are client-specific customization and enhancement capabilities of server content, as well as the dynamic deployment of client-specific protocols on a per-request or per-server basis. We have experimented with a number of Customizers that have been implemented by various members of our laboratory, including an Image Filter, a Remote Cache, a Remote Transaction Recorder, and a Web Page Previewer. The Image Filter reduces image size, and the Remote Cache caches web pages, both at an intermediate server on behalf of the web browsing client, demonstrating how the Customizer architecture could be used to reduce latency of web browsing. The Remote Transaction Recorder maintains a record of browsed Web pages, enabling a wireless client to inspect this record at a later time and thus recover server responses during periods of disconnection after reestablishing connectivity. The Web Page Previewer formats Web pages for previewing them on a small screen such as that of a PDA. This Customizer analyzes HTML code and builds a short preview page, thus reducing the complex page is to an array of links pointing to logical sub-pages of the original site. It is quite sophisticated in that it can deal with scripts, forms, and other complex objects. We have completed performance experiments on the basic Customizer system that show that the basic overhead introduced by Customizers is very small (under 5ms when running on a

"typical" computing hardware) relative to human perception times, and to real Web transaction times where the delays are in the range of 100-500ms. When considering the performance gains the derive from using Customizers, such as reducing the amount of data being sent over the network or reducing the number of requests made to the end servers, it is clear that they provide a major benefit.

Finally, regarding the Mobile-Code Behavior Pattern system, we have completed its design and implementation, which works on top of the Extension system (as the support system for mobile code). We have evaluated the system by building sample mobile-code-based applications, both in terms of the ease of development and to determine the underlying system performance. As for the types of patterns that comprise the current library, we have focused on those that specifically address the problems of mobile wireless resource-challenged devices (as has been our focus with our other work). In particular, the patterns have very specific and limited styles communication and movement.

PERSONNEL SUPPORTED

Faculty

Joseph Pasquale (Professor of Computer Science, U. C. San Diego)

Graduate Students

E. Hung, Ph.D. expected 2004
T. Newhouse, M.S.completed 2001
N. S. Ramabhadran, Ph.D. expected 2005
J. Steinberg, Ph.D. completed 2004

PUBLICATIONS

[HP04] E. Hung and J. Pasquale, "Web Customization Using Behavior-Based Remote Executing Agents," Proc. 13th Intl. World Wide Web Conf. (WWW), May '04

[HP04a] E. Hung and J. Pasquale, "Using Behavior Templates to Design Remotely Executing Agents for Wireless Clients," 4th Workshop on Applications and Services in Wireless Networks (ASWN), Boston, MA, August 2004.

[N01] T. Newhouse, "Java Active Extensions: A mobile-code mechanism for extending client resources," M.S. Dissertation, UC San Diego CSE, Dec. 2001.

[NP04] T. Newhouse and J. Pasquale, "Resource-Controlled Remote Execution to Enhance Wireless Network Applications," 4th Workshop on Applications and Services in Wireless Networks (ASWN), Boston, MA, August 2004.

[PHNSR02] J. Pasquale, E. Hung, T. Newhouse, J. Steinberg, and N. Ramabhadran, "Improving Wireless Access to the Internet By Extending the Client/Server Model," Proc. European Wireless Conference, Florence, Italy, Feb. 2002.

[RP02] N. S. Ramabhadran and J. Pasquale, "A Framework for Application-Specific Customization of Network Services," 4th Intl. Workshop on Active Middleware Services, July '02.

[SP00] Jesse Steinberg and Joseph Pasquale, "Limited Mobile Agents: A Practical Approach," University of California, San Diego Technical Report #CS2000-0641, Jan 2000

[SP02] J. Steinberg and J. Pasquale, "A Web Middleware Architecture for Dynamic Customization of Content for Wireless Clients," Proc. 11th Intl. World Wide Web Conference, Hawaii, May 2002.

[SP04] J. Steinberg and J. Pasquale, "A Flexible Architecture for Customizing Web Streams for Wireless Clients," 4th Workshop on Applications and Services in Wireless Networks, Boston (ASWN), MA, August 2004.

INTERACTIONS/TRANSITIONS

Presentation at AFOSR, 3/3/99
Presentation at DARPA, 3/11/99
Presentation at IDA (Institute Defense Analyses), 4/8/99
Presentation at NSF, 8/8/99
Presentation at DARPA, 2/15/00
Presentation at AFOSR, 4/28/00
Presentation at UC Irvine, 9/30/01
Presentation at DARPA, 1/15/02

NEW DISCOVERIES, INVENTIONS, PATENTS

Java-based Remote Execution Facility (invention, see [NP04])
Web dynamic Proxy System (invention, see [SP02, SP04])
Behavior-based Mobile Code System (invention, see [HP04, HP04a])

HONORS, AWARDS

UCSD Academic Senate Teaching Award (highest university teaching award), 2003